# DESCRIPTION

## OPTICAL SHEET, BACKLIGHT AND LIQUID CRYSTAL DISPLAY APPARATUS

### Technical Field

This invention relates to an optical sheet for enhancing the directivity of light and a backlight and a liquid crystal display apparatus which include the optical sheet.

### Background Art

In recent years, to a liquid crystal display apparatus which includes a liquid crystal panel, it is a significant subject to enhance the display luminance together with reduction of the power consumption in order to raise the commodity value of the liquid crystal display apparatus. In such a situation as just described, it is demanded strongly to improve the optical gain on the backlight side. Thus, it has been proposed, as a method which satisfies the demand, to provide a liquid crystal display apparatus with a prism sheet which includes a prism array on the emitting side of illumination light (refer to, for example, Japanese

Patent No. 3147205).

FIG. 1 shows an external appearance of a conventional prism sheet. FIG. 2 shows a shape of an XZ section of the conventional prism sheet. The prism sheet can separate an incident light ray into a first-order transmission light component T1 which is transmitted directly through a prism lateral face, a return light component R which is reflected by the prism lateral face and then reflected by the other prism lateral face so that it is returned to the incidence side, and a second-order transmission light component T2 which is reflected by the prism lateral face and then transmitted through the other prism lateral face so that it is emitted to a front face of the prism sheet depending upon the incident angle.

The first-order transmission light component T1 is a light flux component which includes light emitted in a front face direction and is utilized effectively. The return light component R is a light flux component which enters and is diffused and reflected by the diffusion sheet, which is regarded as a light emitting face (planar light source), and is effective to increase the luminance of the light emitting face. The second-order transmission light component T2 is a light flux component

which is emitted to the wide angle side outside an effective angular field of view of the liquid crystal panel and does not contribute to enhancement of the luminance.

In this manner, the conventional prism sheet refracts and transmits incident light therethrough to condense the incident light in the front face direction thereby to improve the directivity characteristic so as to increase the front face luminance. Further, since reflected light is diffused and scattered by the diffusing sheet which is regarded as a light emitting face (planar light source) to increase the luminance of the light emitting face, the front face luminance increases.

As described above, the conventional prism sheet can separate an incidence light ray into one of the first-order transmission light component T1, second-order transmission light component T2 and return light component R depending upon the incidence angle of the incidence light.

In the conventional prism sheet, as seen in FIG. 2, part of a light flux emitted from an off-axis imaginary light source is totally reflected by one of lateral faces of the prism sheet and re-enters the other

lateral face, whereafter it advances in the inside of the sheet and is re-utilized as the return light component R. Or, the part of the light flux is effectively utilized, after multiple reflections thereof, as the first-order transmission light component T1 or as the return light component R to the light source side.

However, some light flux emitted from an off-axis imaginary light source is totally reflected by one of lateral faces of the prism sheet and then is refracted by and transmitted through the other lateral face so that it makes the second-order transmission light component T2 which is emitted to the wide angle side outside the effective angular field of view of the liquid crystal panel. The second-order transmission light component T2 is a light flux component which is ineffective to improvement of the luminance.

Further, depending upon the angle dependent characteristic of a polarized light separation sheet disposed on the succeeding stage, extreme deterioration of the polarized light separation characteristic is sometimes caused by the directivity of incident light, which makes an obstacle to effective luminance enhancement to the liquid crystal panel side.

Further, where the prism sheet described above is

interposed between a diffusing sheet and a liquid crystal panel, external appearance blurring appears. Therefore, it is demanded to suppress occurrence of external appearance blurring.

Accordingly, it is a first object of the present invention to provide an optical sheet which implements a high luminance distribution within a predetermined angular field of view and can suppress appearance of a second-order transmission light component T2 to enhance the luminance and a backlight and a liquid crystal display apparatus which include the optical sheet.

It is a second object of the present invention to provide an optical sheet which implements a high luminance distribution within a predetermined angular field of view and can suppress appearance of a second-order transmission light component T2 to enhance the luminance and besides can suppress, where a prism sheet is provided between a diffuser and a liquid crystal panel, appearance of external appearance blurring and a backlight and a liquid crystal display apparatus which include the optical sheet.

## Disclosure of Invention

The inventor of the present invention has studied

hard in order to solve the subjects described above which the prior art has. An outline is described below.

According to the knowledge of the inventor of the present invention, with a conventional prism sheet, some second order transmission light enters an adjacent prism and hence re-enters the inside of the sheet, and consequently is added to and re-utilized together with return light. Further, some second order transmission light is effectively utilized as first order transmission light or return light to the light source side after multiple reflection. In contrast, some second order transmission light, so-called side robe light, is not utilized effectively. Most of such second order transmission lights are generated when light incident from an oblique direction with respect to a principal surface of a prism sheet is totally reflected by one of faces of a prism and then refracted by and transmitted through the other face of the prism.

Further, according to the knowledge of the inventor, light incident on a portion of the prism in the proximity of a vertex from a direction perpendicular to the principal face of the prism sheet is totally reflected, and therefore, the first order transmission light decreases.

Therefore, the inventor has studied hard with regard to an interface which can forwardly refract and transmit light incident on a portion of a prism in the proximity of a vertex from a direction perpendicular to a principal face of a prism sheet to increase the first order transmission light while it totally reflects light incident from a direction oblique to the principal face of the prism sheet at one face thereof and then totally reflects or refracts and transmits the totally reflected light at the other face thereof to increase the return light. As a result, the inventor has invented an interface wherein a large number of cylindrical lens elements having a hyperboloidal surface or a paraboloidal surface are juxtaposed in a direction perpendicular to a generating line of the cylindrical lens elements.

The present invention has been made based on the studies described above.

In order to solve the subject described above, according to a first aspect of the present invention, there is provided an optical sheet having cylindrical lens elements which have a high-order aspheric face and are provided successively in a row on one of principal faces of the optical sheet, characterized in that,

where a Z axis is taken in parallel to a normal

line direction to the optical sheet and an X axis is taken in a direction of the row of the cylindrical lens elements, a cross sectional shape of the cylindrical lenses satisfies the following expression:

$$Z = X^2/(R + \sqrt{(R^2 - (1 + K)X^2)}) + AX^4 + BX^5 + CX^6 + \cdots$$

(where R is the radius of curvature of a distal end vertex, K is a conic constant, and A, B, C, ⋯ are aspheric coefficients.)

According to a second aspect of the present invention, there is provided a backlight, characterized in that the backlight comprises:

a light source for emitting illumination light; and

an optical sheet for raising the directivity of the illumination light emitted from the light source; that

the optical sheet has, on the illumination light emission side thereof, cylindrical lens elements which have a high-order aspheric face and are provided successively in a row; and that, where a Z axis is taken in parallel to a normal line direction to the optical sheet and an X axis is taken in a direction of the row of the cylindrical lens elements, a cross sectional shape of

the cylindrical lenses satisfies the following expression:

$$Z = X^2/(R + \sqrt{}(R^2 - (1 + K)X^2)) + AX^4 + BX^5 + CX^6 + \cdots$$

(where R is the radius of curvature of a distal end vertex, K is a conic constant, and A, B, C, ⋯ are aspheric coefficients.)

According to a third aspect of the present invention, there is provided a liquid crystal display apparatus, characterized in that the liquid crystal display apparatus comprises: a light source for emitting illumination light; an optical sheet for raising the directivity of the illumination light emitted from the backlight; and a liquid crystal panel for displaying an image based on the illumination light emitted from the optical sheet; that the optical sheet has, on the illumination light emission side thereof, cylindrical lens elements which have a high-order aspheric face and are provided successively in a row; and that, where a Z axis is taken in parallel to a normal line direction to the optical sheet and an X axis is taken in a direction of the row of the cylindrical lens elements, a cross sectional shape of the cylindrical lenses satisfies the following expression:

$$Z = X^2/(R + \sqrt{(R^2 - (1 + K)X^2)}) + AX^4 + BX^5 + CX^6 + \cdots$$

(where R is the radius of curvature of a distal end vertex, K is a conic constant, and A, B, C, … are aspheric coefficients.)

In the first, second and third aspects of the present invention, preferably the radius R of curvature, the conic constant K and the aspheric coefficients A, B, C, … satisfy the following numerical ranges:

$R \geqq 0$

$K < -1$

$0 < A < 10^{-3}$

$0 \leqq B, C \cdots < 10^{-3}$

In the first, second and third aspects of the present invention, preferably the radius R of curvature, the conic constant K and the aspheric coefficients A, B, C, … satisfy the following numerical ranges:

$0 < R \leqq 72$

$-15 < K \leqq -1$

$R - K \geqq 5$

$0 \leqq A, B, C \cdots < 10^{-3}$

4. An optical sheet according to claim 1, characterized in that the radius R of curvature, the conic constant K and the aspheric coefficients A, B, C, …

satisfy the following numerical ranges:

$0 < R \leqq 30$

$-15 < K \leqq -1$

$R - K \geqq 5$

$0 \leqq A, B, C \cdots < 10^{-3}$

In the first, second and third aspects of the present invention, preferably convex portions having a height equal to or greater than 0.20 μm from an average central plane are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements are provided, and that the density of the convex portions is equal to or higher than 70 /mm$^2$ but equal to or lower than 500 /mm$^2$.

In the first, second and third aspects of the present invention, preferably convex portions having a height equal to or greater than 0.20 μm from an average central plane are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements are provided, and that the average distance between the convex portions is equal to or greater than 50 μm but equal to or smaller than 120 μm.

In the first, second and third aspects of the present invention, preferably convex portions are further provided on the other principal face side opposite to the

one principal face on which the cylindrical lens elements are provided, and that the convex portions are provided such that, in a state wherein the cylindrical lens elements are not formed, the cloudiness degree of the optical sheet is equal to or lower than 60%.

In the first, second and third aspects of the present invention, preferably convex portions are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements are provided, and that the convex portions are provided such that, in a state wherein the cylindrical lens elements are not formed, the cloudiness degree of the optical sheet is equal to or lower than 20%.

In the first, second and third aspects of the present invention, preferably convex portions are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements are provided, and that the ten-point average roughness SRz of the convex portions is equal to or higher than 1 μm but equal to or lower than 15 μm.

In the first, second and third aspects of the present invention, preferably convex portions are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements

are provided, and that the height of the convex portions at which the convex portion area occupies 1% is equal to or greater than 1 μm but equal to or smaller than 7 μm.

In the first, second and third aspects of the present invention, preferably convex portions are further provided on the other principal face side opposite to the one principal face on which the cylindrical lens elements are provided, and that the average inclination gradient of the face on the side on which the convex portions are provided is equal to or greater than 0.25.

In the first, second and third aspects of the present invention, the optical sheet can refract and transmit light incident from a direction perpendicular to a principal face thereof by a comparatively great amount to a forward direction. Besides, the optical sheet can totally reflect light incident from an oblique direction with respect to the principal face thereof at one of faces thereof and then totally reflect or refract and transmit the totally reflected light at the other principal face to form return light.

Further, since the convex portions are provided on the other principal face on the opposite side to the one principal face on which the cylindrical lens elements are provided, also where the optical sheet is provided on

a diffuser, the optical sheet can be preventing from adhering to the diffuser.

As described above, according to the present invention, the directivity can be improved to enhance the front face luminance to achieve contribution to the enhancement of the characteristic by the polarized light separation sheet on the succeeding stage. Consequently, the display luminance of the liquid crystal panel can be enhanced together with reduction of the power consumption.

Further, since the second order transmission light flux component T2 to be emitted to the wide angle is reduced, the front face luminance can be enhanced to achieve contribution to the enhancement of the characteristic by the polarized light separation sheet on the succeeding stage. Consequently, the display luminance of the liquid crystal panel can be enhanced together with reduction of the power consumption.

Further, the incident angle of the illumination light flux to the liquid crystal panel itself can be controlled to the normal line direction, and the color separation (blurring in color) on the wide angle side can be controlled.

Further, since the convex portions are provided on the other principal face on the opposite side to the

one principal face on which the cylindrical lens elements are provided, where the optical sheet is provided in the liquid crystal display apparatus, appearance of external appearance blurring can be suppressed. Further, since the sliding characteristic can be enhanced, appearance of damage to the rear face of the lens sheet and to another sheet disposed in an opposing relationship to the rear face can be suppressed.

Brief Description of Drawings

FIG. 1 is a perspective view showing an external appearance of a prism sheet;

FIG. 2 is a schematic view showing an XZ section of the prism sheet;

FIG. 3 is a cross sectional view showing an example of a configuration of a liquid crystal display apparatus according to an embodiment of the present invention;

FIG. 4 is a perspective view showing an example of a shape of a lens sheet according to the embodiment of the present invention;

FIG. 5 is a schematic view showing an example of a configuration of an extruded sheet precision molding apparatus used in a production method for an optical film

according to the embodiment of the present invention;

FIG. 6 is a schematic view showing part of an XZ section of a conventional prism sheet in an enlarged scale;

FIG. 7 is a distribution diagram illustrating a light distribution characteristic of a conventional prism sheet;

FIG. 8 is a distribution diagram illustrating a visual field characteristic of a conventional prism sheet;

FIG. 9 is a schematic view showing part of an XZ section of a lens sheet of a working example 1 in an enlarged scale;

FIG. 10 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 1;

FIG. 11 is a schematic view showing part of an XZ section of a lens sheet of a working example 2 in an enlarged scale;

FIG. 12 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 2;

FIG. 13 is a schematic view showing part of an XZ section of a lens sheet of a working example 3 in an

enlarged scale;

FIG. 14 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 3;

FIG. 15 is a schematic view showing part of an XZ section of a lens sheet of a working example 4 in an enlarged scale;

FIG. 16 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 4;

FIG. 17 is a schematic view showing part of an XZ section of a lens sheet of a working example 5 in an enlarged scale;

FIG. 18 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 5;

FIG. 19 is a schematic view showing part of an XZ section of a lens sheet of a working example 6 in an enlarged scale;

FIG. 20 is a distribution diagram illustrating a light distribution characteristic of the lens sheet of the working example 6;

FIG. 21 is a schematic view showing part of an XZ section of a lens sheet of a working example 7 in an

enlarged scale;

FIG. 22 is a distribution diagram illustrating an orientation characteristic of the lens sheet of the working example 7;

FIG. 23 is a graph illustrating a peak luminance distribution where K = -1;

FIG. 24 is a graph illustrating a peak luminance distribution where K = -1.5;

FIG. 25 is a graph illustrating a peak luminance distribution where K = -2;

FIG. 26 is a graph illustrating a peak luminance distribution where K = -5;

FIG. 27 is a graph illustrating a peak luminance distribution where K = -10;

FIG. 28 is a graph illustrating a peak luminance distribution where K = -15;

FIG. 29 is a graph illustrating a peak luminance distribution where K = -20;

FIG. 30 is a table illustrating a result of evaluation of lens sheets;

FIG. 31 is a table illustrating a result of evaluation of lens sheets;

FIG. 32 is a graph illustrating a relationship between the number of convex portions of a size equal to

or greater than 0.2 μm and the luminance relative value;

FIG. 33 is a graph illustrating the number of convex portions of a size equal to or greater than 0.2 μm and the external appearance blurring;

FIG. 34 is a graph illustrating a relationship between the distance between convex portions of a size equal to or greater than 0.2 μm and the luminance relative value;

FIG. 35 is a graph illustrating a relationship between the distance between convex portions of a size equal to or greater than 0.2 μm and a result of a sliding test;

FIG. 36 is a graph illustrating a relationship between the distance between convex portions of a size equal to or greater than 0.2 μm and the external appearance blurring;

FIG. 37 is a graph illustrating a relationship between the ten-point average roughness SRz and the luminance relative value;

FIG. 38 is a graph illustrating a relationship between the ten-point average roughness SRz and a result of a sliding test;

FIG. 39 is a graph illustrating a relationship between the height at which the convex portion area

occupies 1% and the luminance relative value;

FIG. 40 is a graph illustrating the height at which the convex portion area occupies 1% and a result of the sliding test;

FIG. 41 is a graph illustrating a relationship between the haze and the luminance relative value; and

FIG. 42 is a graph illustrating a relationship between the average inclination gradient and the luminance relative value.

## Best Mode for Carrying out the Invention

In the following, an embodiment of the present invention is described with reference to the drawings. It is to be noted that, in all of the figures of the embodiment described below, like or corresponding elements are denoted by like reference characters.

### Configuration of a Liquid Crystal Display Apparatus

FIG. 3 is a sectional view showing an example of a configuration of a liquid crystal display apparatus according to an embodiment of the present invention. Referring to FIG. 3, the liquid crystal display apparatus includes a backlight 1 and a liquid crystal panel 2. While it is described here that the backlight 1 is of the direct type, the backlight 1 may be of the edge light

type (side light type).

The backlight 1 is for supplying light to the liquid crystal panel 2 and is disposed directly below the backlight 1. The liquid crystal panel 2 is for temporally and spatially modulating the light supplied thereto from the backlight 1 to display information. A pair of polarizing plates 2a and 2b are provided on the opposite faces of the liquid crystal panel 2. Each of the polarizing plate 2a and the polarizing plate 2b transmit one of orthogonally polarized light components of incident light therethrough and intercept the other one of the orthogonally polarized light components by absorption. The polarizing plate 2a and the polarizing plate 2b are provided such that, for example, the transmission axes thereof are orthogonal to each other.

As seen in FIG. 3, the backlight 1 includes, for example, a reflecting plate 11, one or more light sources 12, a diffuser 13, a diffusing sheet 17, a lens sheet 14, and a reflection type polarizer 18. The one or plural light sources 12 are for supplying light to the liquid crystal panel 2 and are each in the form of, for example, a fluorescent lamp (FL), an EL (Electro Luminescence) element or an LED (Light Emitting Diode).

The reflecting plate 11 is provided such that it

covers the one or plural light sources 12 from below and sidewardly and is for reflecting light emitted downwardly or sidewardly from the one or plural light sources 12 to direct the light toward the liquid crystal panel 2. It is to be noted that a chassis may be provided in place of the reflecting plate 11.

The diffuser 13 is provided above the one or plural light sources 12 and is for diffusing emitted light from the one or light sources 12 and reflected light from the reflecting plate 11 to make the luminance uniform.

The diffusing sheet 17 is provided on the diffuser 13 and is for at least diffusing the light diffused by the diffuser 17. Further, the diffusing sheet 17 may additionally have a function of condensing light.

The lens sheet 14 which is an example of an optical sheet is provided above the diffuser 13 and is for enhancing the directivity and so forth of illumination light.

The reflection type polarizer 18 is provided on the lens sheet 14 and is for transmitting one of orthogonally polarized light components of the light whose directivity has been enhanced by the lens sheet 14

while reflecting the other one of the orthogonally polarized light components.

In the following, a configuration of the lens sheet 14 described above is described in more detail.

Configuration of the Lens Sheet

FIG. 4 is a perspective view showing an example of a shape of the lens sheet 14 according to the embodiment of the present invention. Referring to FIG. 4, the lens sheet 14 has a form of a sheet and has, for example, a quadrangular shape as viewed from a principal face side thereof. In the present specification, a sheet includes not only a film-like sheet but also sheets having various forms of thin plates having flexibility or some degree of hardness.

In the following description, one principal face of the lens sheet 14 on the side on which light from the light sources 12 is incident is referred to as rear face, and the other principal face on the side from which light from the light sources 12 is emitted is referred to as front face.

A plurality of convex portions 16 are provided on the rear face side of the lens sheet 14, and a large number of cylindrical lens elements 15 having a leftwardly and rightwardly symmetrical hyperboloidal face

or paraboloidal face are juxtaposed in a direction perpendicular to the generating line of the hyperboloidal faces or paraboloidal faces on the front face side of the lens sheet 14. The cylindrical lens elements 15 have one focal distance fa on the side thereof from which light from the light sources 12 is emitted. It is to be noted that, as shown in FIG. 4, an X axis is taken in parallel to the direction of the row of the cylindrical lens elements 15; a Y axis is taken in parallel to the direction of the generating line of the cylindrical lens elements 15; and a Z axis is taken in parallel to the normal line direction to the lens sheet 14.

The width of the cylindrical lens elements 15 provided on the front face side of the lens sheet 14, that is, a configuration unit width (pitch) D, is selected from within a range of 10 to 120 μm, and preferably selected in accordance with pixels of the liquid crystal panel. For example, where the lens sheet 14 is used for a liquid crystal television set or a liquid crystal monitor for a personal computer, the configuration unit width (pitch) D is selected preferably within a range of 50 to 100 μm. On the other hand, where the lens sheet 14 is used for a monitor for a portable apparatus, the configuration unit width D is preferably

selected from within another range of 10 to 80 μm.

It is to be noted that the lens sheet 14 is provided between the diffuser 13 and the liquid crystal panel 2 such that the side thereof on which the plural cylindrical lens elements 15 are provided is opposed to the liquid crystal panel 2.

Further, the shape of an XZ section of the cylindrical lens elements 15 satisfies the following expression (1):

$$Z = X^2/(R + \sqrt{}(R^2 - (1 + K)X^2)) + AX^4 + BX^5 + CX^6 + \cdots (1)$$

where R is the radius of curvature of a distal end vertex of the cylindrical lens elements 15, K is a conic constant, and A, B, C ⋯ are aspheric coefficients. It is to be noted that, in the present specification, "√" signifies a square root of a value determined by a numerical expression following the same.

In the expression (1), the radius R of curvature of the distal end vertex, the conic constant K and the aspheric coefficients A, B, C, … are preferably set to values within numerical ranges of $0 < R \leqq 72$, $-15 < K \leqq -1$, $R - K \geqq 5$, and $0 \leqq A, B, C \ldots < 10^{-3}$. By defining the factors mentioned within such numerical ranges as specified above, the directivity of the illumination

light can be raised.

Further, where the configuration unit width D is D = 50 μm, in the expression (1), the radius R of curvature of the distal end vertex, the conic constant K and the aspheric coefficients A, B, C, … are preferably set to values within numerical ranges of $0 < R \leqq 30$, $-15 < K \leqq -1$, $R - K \geqq 5$, and $0 \leqq A, B, C \ldots < 10^{-3}$. By defining the factors mentioned within such numerical ranges as specified above, the directivity of the illumination light can be raised.

Further, in the expression (1), the radius R of curvature of the distal end vertex, the conic constant K and the aspheric coefficients A, B, C, … are preferably set to values within numerical ranges of $R \geqq 0$, $K < -1$, $0 < A < 10^{-3}$, and $0 \leqq B, C \ldots < 10^{-3}$. By defining the factors mentioned within such numerical ranges as specified above, the directivity of the illumination light and the angular of view can be raised.

Where the configuration unit width D is D = 20 μm, the radius R of curvature of the distal end vertex and the conic constant K are preferably set to values within numerical ranges of $0 < R \leqq 12$ μm, $-15 < K \leqq -1$, $R - K \geqq 5$, and $0 < A, B, C \cdots < 10^{-3}$.

Where the configuration unit width D is D = 80 μm,

the radius R of curvature of the distal end vertex and the conic constant K are preferably set to values within numerical ranges of $0 < R \leqq 48$ μm, $-15 < K \leqq -1$, $R - K \geqq 5$, and $0 < A, B, C \cdots < 10^{-3}$.

The height of the convex portions 16 provided on the rear face of the lens sheet 14 is preferably set equal to or more than 0.20 μm from an average center plane (JIS B0601-1994). Further, the density of the convex portions 16 having a height of 0.20 μm or more from the average center plane is preferably set to a value equal to or higher than 70 /$mm^2$ but equal to or lower than 500 /$mm^2$. Further, the average distance of the convex portions 16 having a height of 0.20 μm or more from the average center plane is preferably set to a value within a region equal to or higher than 50 μm but equal to or lower than 120 μm.

Further, the convex portions 16 provided on the rear face of the lens sheet 14 are preferably provided such that, in a state wherein the cylindrical lens elements 15 are not formed, the degree of cloudiness of the lens sheet 14 is equal to or lower than 60%, and more preferably provided such that the degree of cloudiness of the lens sheet 14 is equal to or lower than 20%.

Furthermore, the convex portions 16 provided on

the rear face of the lens sheet 14 are preferably provided such that the ten-point average roughness SRz is set to a value within a range equal to or higher than 1 μm but equal to or lower than 15 μm. Further, the convex portions 16 on the one principal face side of the lens sheet 14 are preferably provided such that the height thereof at which the convex portion area occupies 1% is set to a value equal to or greater than 1 μm but equal to or smaller than 7 μm.

Now, a method of producing the lens sheet according to the embodiment of the present invention is described.

First, an extruded sheet precision molding apparatus for use with the production method for the lens sheet according to the embodiment of the present invention is described with reference to FIG. 5.

Configuration of the Extruded Sheet Precision Molding Apparatus

Referring to FIG. 5, the extruded sheet precision molding apparatus includes an extruder 21, a T die 22, a forming roll 23, an elastic roll 24 and a cooling roll 25.

For molding of the lens sheet 14, at least one kind of transparent thermoplastic resin is used. As the thermoplastic material, a thermoplastic material having a

refractive index of 1.4 or more is preferably used taking a function of controlling the light emitting direction into consideration. As such resins, for example, a polycarbonate resin, an acrylic resin represented by a polymethyl methacrylate resin, a polyester resin or an amorphous copolymer polyester resin represented by polyethylene terephthalate, a polystyrene resin, a polyvinylchloride resin and so forth can be listed.

Further, where the transfer performance of a lens pattern by a melt extrusion method is taken into consideration, more preferably the melt viscosity around a molding temperature is equal to or higher than 1,000 Pa but equal to or lower than 10,000 Pa.

Furthermore, at least one kind of release agent is preferably contained in the thermoplastic resin. Where a release agent is contained in this manner, the close contact property between the forming roll 23 and a sheet when the sheet is to be exfoliated from the forming roll 23 can be adjusted to prevent an exfoliation line from being formed on the lens sheet 14.

The amount of the release agent to be added to the thermoplastic material is preferably equal to or more than 0.02 wt% but equal to or smaller than 0.4 wt%. If the amount decreases further than 0.02 wt%, then the

releasability is deteriorated and an exfoliation line is formed on the lens sheet 14. On the other hand, where the amount increases further than 0.04 wt%, then the releasability becomes excessively high. Consequently, before the transparent thermoplastic resin cures, it is exfoliated from the forming roll 23, resulting in a failure that the shape of the cylindrical lens elements 15 is deformed.

Further, at least one kind of ultraviolet absorbing agent or light stabilizer is contained in the thermoplastic resin. Where the ultraviolet absorbing agent or light stabilizer is contained in this manner, a color change of the thermoplastic resin by light irradiation from a light source can be suppressed.

The amount of the ultraviolet absorbing agent or light stabilizer to be added to the thermoplastic resin is preferably equal to or greater than 0.02 wt% but equal to or lower than 0.4 wt%. Where the amount decreases further than 0.02 wt%, it becomes impossible to suppress a hue change. On the other hand, where the amount increases further than 0.4 wt%, the lens sheet 14 becomes yellowish.

As the ultraviolet absorbing agent, ultraviolet absorbing agents of the salicylic acid type, benzophenone

type, benzotriazole type, cyanoacrylate type and so forth can be listed. More particularly, for example, Adekastab LA-31, Adekastab LA-32 (by ADEKA Corporation), Cyasorb UV-5411 (by Sun Chemical Company Ltd.), Tinuvin P, Tinuvin 234, Tinuvin 320, Tinuvin 327 (by Nihon Ciba-Geigy K.K.), Sumisorb 110, Sumisorb 140 (by Sumitomo Chemical Co., Ltd.), Kemisorb 110, Kemisorb 140, Kemisorb 12, Kemisorb 13 (by Chemipro Kasei Kaisha, Ltd.), Uvinul X-19, Uvinul Ms-40 (by BASF), Tomisorb 100, Tobisorb 600 (by Yoshitomi Pharmaceutical Industries, Ltd.), Viosorb-90 (by Kyodo Chemical Co., Ltd.) and so forth are listed. Meanwhile, as the light stabilizer, a hindered amine light stabilizer and so forth are listed, and more particularly, for example, Adekastab LA-52 (by ADEKA Corporation), Sanol LS-770, Sanol LS-765, Sanol Ls774 (by Sankyo Co., Ltd.), Sumisorb TM-061 (by Sumitomo Chemical Co., Ltd.) and so forth are listed.

Further, also it is possible to add, in addition to the release agent and the ultraviolet absorbing agent described above, such an additive as an anti-oxidizing agent, an antistatic agent, a coloring agent, a plasticizer, a compatibilizer, a fire retardant or the like. However, most additives make a factor of generation of gas upon heating in melt extrusion of the T

die 22 or the like and give rise to deterioration of the film formation or of the working environment. Therefore, the total amount of additives is preferably minimized, and the amount of additives to be added to a thermoplastic resin is preferably set equal to or smaller than 2 wt%.

The extruder 21 melts a resin material supplied thereto from a hopper not shown and supplies the molten resin material to the T die 22. The T die 22 has a "-" shaped opening, and expands the resin material supplied thereto from the extruder 21 so as to have a width of a sheet to be molded and discharges the expanded resin material.

The forming roll 23 has a cylindrical shape and is configured to be driven to rotate around an axis of rotation which is a center axis thereof. Further, the forming roll 23 is configured so as to be cooled. In particular, the forming roll 23 has one, two or more flow paths for circulation of a coolant in the inside thereof. As the coolant, for example, an oil medium is used, and the temperature of this oil medium is varied within a range, for example, from 120°C to 230°C.

A sculpture shape for transferring a fine pattern to a sheet discharged from the T die 22 is provided on a

cylindrical surface of the forming roll 23. The sculpture shape is a fine concave and convex shape for transferring, for example, the cylindrical lens elements 15 to a sheet. The concave and convex shape is formed, for example, by precision cutting by means of a diamond cutting tool. Further, the sculpture shape is formed toward a circumferential direction or a widthwise direction (heightwise direction) of the forming roll 23 having a cylindrical shape.

The elastic roll 24 has a cylindrical shape and is configured to be driven to rotate around an axis of rotation which is the center axis thereof. Further, the surface of the elastic roll 24 is formed for elastic deformation such that, when a sheet is nipped by the forming roll 23 and the elastic roll 24, a face of the elastic roll 24 contacting with the forming roll 23 is elastically deformed into a squashed state.

The elastic roll 24 is covered with a seamless tube formed from, for example, plated Ni, and a resilient member for allowing the surface of the elastic roll 24 to be elastically deformable is provided in the inside of the elastic roll 24. The configuration and the material of the elastic roll 24 are not limited particularly only if the surface of the elastic roll 24 elastically deforms

when it contacts with the forming roll 23 with a predetermined pressure. For example, a rubber material, a metal material or a composite material may be used as the material. The elastic roll 24 is not limited to a roll-shaped one, but a belt-shaped one may be used.

When the convex portions 16 are to be provided on the rear face of the lens sheet 14, recesses for forming the convex portions 16 on the rear face side of the lens sheet 14 are provided on the cylindrical face of the elastic roll 24. The elastic roll 24 is configured so as to be cooled. In particular, the elastic roll 24 has one, two or more flow paths for circulation of a coolant in the inside thereof. As the coolant, for example, water can be used. Then, a temperature regulator of the pressurized hot water type not shown is used to set the basic temperature, for example, to 80°C and 130°C. It is to be noted that an oil temperature regulator may be used as the temperature regulator.

The cooling roll 25 has a cylindrical shape and is configured to be driven to rotate around an axis of rotation which is the center axis thereof. The cooling roll 25 is configured so as to be cooled. In particular, the cooling roll 25 has one, two or more flow paths for circulation of a coolant in the inside thereof. As the

coolant, for example, water can be used. Then, a temperature regulator of the pressurized hot water type not shown is used to set the basic temperature, for example, to 115°C. It is to be noted that an oil temperature regulator may be used as the temperature regulator.

<u>Production Method for the Lens Sheet</u>

A production method for a lens sheet according to the embodiment of the present invention is described below.

First, a resin material is melted by the extruder 21 and successively supplied to the T die 22 so that a sheet is discharged continuously from the T die 22.

Then, the sheet discharged from the T die 22 is nipped by the forming roll 23 and the elastic roll 24. Consequently, the sculpture shape of the forming roll 23 is transferred to the front face of the sheet while the concave and convex shape of the elastic roll 24 is transferred to the rear face of the sheet. Thereupon, the surface temperature of the forming roll 23 is kept within a temperature range from Tg + 20°C to Tg + 45°C, and the surface temperature of the elastic roll 24 is kept within another temperature range from 20°C to Tg°C. Here, Tg is a glass transition temperature of the resin

material. Since the surface temperatures of the forming roll 23 and the elastic roll 24 are kept within the temperature ranges specified as above, the sculpture shape can be transferred well to the sheet. Further, the temperature of the resin material when the sculpture shape is transferred to the sheet is preferably set to Tg + 50°C to Tg + 230°C and more preferably set to Tg + 80°C to Tg + 200°C. Where the temperature of the resin is kept within the temperature range specified above, the sculpture shape can be transferred well to the sheet.

Then, while the sheet is nipped by the forming roll 23 and the cooling roll 25 to suppress fluttering thereof, the sheet is exfoliated from the forming roll 23 by the cooling roll 25. Thereupon, the surface temperature of the cooling roll 25 is kept within a temperature range equal to or lower than Tg. Where the surface temperature of the cooling roll 25 is kept within such a temperature range as specified above and the sheet is nipped by the forming roll 23 and the cooling roll 25 to suppress fluttering thereof, the sheet can be exfoliated well from the forming roll 23. Further, the temperature of the resin material upon exfoliation is preferably equal to or higher than Tg, and more preferably is Tg + 20°C to Tg + 85°C and still more

preferably is Tg + 30°C to Tg + 60°C. Where the temperature of the resin is kept within such a temperature range as specified just above and the sheet is nipped by the forming roll 23 and the cooling roll 25 to suppress fluttering thereof, the sheet can be exfoliated well from the forming roll 23. According to the foregoing, an object lens sheet can be obtained.

According to the embodiment of the present invention, the following effects can be achieved.

In a conventional production method for a lens sheet, a lens shape is formed principally with a UV (ultraviolet rays) curing resin (for example, a UV curing acrylic resin or the like) on a film substrate of polyethylene terephthalate (PET) or the like. This production method has problems that the UV curing resin is expensive and that, since it is necessary to perform UV irradiation sufficiently on the UV curing resin in order to harden the resin, the production speed is low. Further, the production method has a problem also that, since a two-layer structure of a sheet and a lens layer is used, warping is liable to occur due to the difference in expansion coefficient by the heat or temperature and the assembly process is complicated.

Against the problems, the lens sheet production

method according to the present embodiment can achieve, because it uses an integrated molded article by thermal transfer to a thermoplastic resin, such special effects that a less expensive material can be used, that the productivity of a lens sheet can be enhanced and that also appearance of warping on a lens sheet can be suppressed.

In the following, the present invention is described in connection with working examples. However, the present invention is not limited only to the working examples.

The inventor of the present invention performed a study through a simulation in which the numerical values of the radius R of curvature, the conic constant K and the aspheric coefficients A, B, C ··· in the expression (1) given hereinabove were varied in order to define the radius R of curvature, the conic constant K and the aspheric coefficients A, B, C ···.

<u>Conventional Example</u>

FIG. 6 shows part of an XZ section of a prism sheet of a conventional example in an enlarged scale. A plurality of very small prisms are provided successively on the surface of the prism sheet. It is to be noted that, in FIG. 6, a point A indicates a vertex of a prism,

and another point B and a further point C indicate each a joining point with an adjacent prism, and a still further point O is an imaginary light start point just below the vertex A. A yet further point P indicates an imaginary light start point just below the joining point B. Further, in the following description, a face between the vertex A and the joining point B is referred to as AB face, and a face between the vertex A and the joining point C is referred to as AC face.

Further, FIG. 6 shows a locus of a light flux Ω which enters the AB face from the imaginary light start point O and a locus of another light flux Ψ which enters the AB face and the AC face from the imaginary light start point P. The loci of the light flux Ω and the light flux Ψ were determined through a simulation. It is to be noted that, also in the working examples hereinafter described, like or corresponding elements are denoted by like reference characters.

FIG. 7 illustrates a luminous intensity distribution characteristic of the prism sheet of the conventional example. FIG. 8 illustrates a visual field characteristic of the prism sheet of the conventional example. It is to be noted that, in FIGS. 7 and 8, a distribution surrounded by a framework t1 corresponds to

the first order transmission light, and a distribution surrounded by another framework t2 corresponds to the second order transmission light. The distribution diagram of FIG. 7 shows circles whose center is set to 0°C and indicate angles such that the first circle from the center indicates an angle of 10°, the second circuit indicates another angle of 20°, ⋯, and the outermost circle indicates 90°. Further, the distribution diagrams of FIGS. 7 and 8 are drawn through a computer simulation. Also the distribution diagrams of the working examples hereinafter described depend upon a simulation similarly.

From FIG. 7, it can be confirmed in what angle light emitted from the prism sheet expands. Further, it can be seen that a distribution corresponding to the second order transmission light T2 appears in the proximity of 70° above and below the center. Further, from FIG. 8, it can be seen that the angular field of view by the half value width with respect to the front face luminance is approximately 100°.

Then, a prism of a triangular shape described hereinabove was produced on the one principal face of the sheet by a melt extrusion method, and the shape of the prism was evaluated.

In the following, a production method for a lens

sheet by the melt extrusion method is described particularly.

First, the elastic roll was produced in the following manner. A seamless tube was formed by Ni plating, and a Cr plating process was performed for the surface of the seamless tube. Thereafter, the plated Cr layer was polished to 0.2 S to produce a seamless tube (hereinafter referred to as flexible sleeve) having a thickness of 340 microns.

Then, a resilient member was adhered to a roll in which coolant can be circulated, and the flexible sleeve was fitted on the resilient member to obtain an elastic roll having a configuration that cooling water can be circulated between the resilient member and the flexible sleeve. It is to be noted that the resilient member was made of nitrile-butadiene rubber (NBR) having a hardness of 85 degrees with a thickness of 20 mm. Further, the diameter Φ of the elastic roll was set to 260 mm, and the face length (width of the forming roll) was set to 450 mm.

Thereafter, a forming roll having a structure wherein coolant can be circulated in the inside thereof through a plurality of flow paths so that the temperature distribution can be reduced was prepared. It is to be noted that the material was S45C and was subject to

hardening and tempering and then to mirror finish (equal to or less than 0.5 S) and an electroless NiP (Nickel and Phosphorus) plating (100 microns thick) process.

A sculpture shape was formed on the cylindrical face of the forming roll in the following manner. First, a diamond cutting tool having a predetermined shape was set in position on a superfine lathe wherein the forming roll was placed in a chamber of a constant temperature and a constant humidity (temperature 23°C, humidity 50%). Then, lens patterns of the prism of the triangular shape described above were formed in a circumferential direction of the forming roll. It is to be noted that the forming roll has a diameter of Φ300, a face length of 460 mm and a groove working width of 300 mm.

An oil medium was used as the coolant for the forming roll. Water was used as the coolant for the elastic roll and the cooling roll, and a temperature regulator of the pressurized hot water type was used to regulate the temperature of the coolants.

As the extruder, an extruder including a screw with a vent having a diameter of Φ50 mm and having no gear pump was used. Further, as the T die, a coach hanger type die was used, and the lip width of the same was 550 mm and the lip gap was 1.5 mm. Further, the air

gap was 105 mm.

The extruded sheet precision molding apparatus having the configuration described above was used to perform molding of a lens sheet.

First, the polycarbonate E2000R (by Mitsubishi Engineering-Plastic Corporation) was extruded from the T die. Then, the material was nipped by the forming roll and the elastic roll and then wrapped around the forming roll. It is to be noted that the surface temperature of the forming roll was kept at Tg + 35°C, and the surface temperature of the elastic roll was kept at 75°C. Here, Tg is the glass transition temperature of the polycarbonate resin.

Thereafter, the sheet was exfoliated from the forming roll by the cooling roll. It is to be noted that the surface temperature of the cooling roll was kept at 115°C. Further, the speed of a takeup apparatus was 7 m/min. As a result of the foregoing, a lens sheet of a thickness of 220 microns having grooves transferred to one of the principal faces thereof was obtained.

The surface temperatures of the forming roll and the elastic roll described above were obtained such that a sensor was contacted with the roll surfaces to perform measurement at a position immediately preceding to the

nit point at which the measurement is least likely to be influenced by the heat of the resin. Meanwhile, the surface temperature of the cooling roll was obtained such that a sensor was contacted with the surface of the cooling roll to perform measurement at a position at which the film is nipped by the cooling roll and the forming roll. It is to be noted that, as the thermometers, a handy type digital thermometer (by Chino, commodity name: ND511-KHN) was used, and as the sensors, a sensor for surface temperature measurement (by Anritsu Meter Co., Ltd., commodity name U-161K-00-D0-1) was used.

Thereafter, the prism lens formed on one of the principal surfaces of the prism sheet in such a manner as described above and the prism lens described hereinabove with reference to FIG. 6 were compared with each other in shape. As a result, it was found that a desired lens shape was not successfully obtained because it was impossible to cause the thermoplastic resin to advance into a vertex portion of the lens pattern of the prism of the triangular shape.

Working Example 1

(Where $R = 3$, $K = -2$, $A = 10^{-5}$, $B, C \cdots = 0$)

FIG. 9 shows part of an XZ section of a lens sheet of a working example 1 in an enlarged scale. A

large number of cylindrical lens elements having a finite focal distance on the emission side of illumination light and having a leftwardly and rightwardly symmetrical, high-order aspheric face are arrayed successively on the lens sheet. The aspheric sectional shape is represented by $Z = X^2/(3 + \sqrt{(9 + X^2)}) + 10^{-5}X^4$ which satisfies the expression (1).

In the following, action and effects of the lens sheet of the working example 1 with respect to a light flux $\Omega$ incident from a perpendicular direction and another light flux $\Psi$ incident from a sideward direction are described with reference to FIG. 9.

<u>Light Flux $\Omega$ Incident from a Perpendicular Direction</u>

First, action and effects of the lens sheet with respect to a light flux $\Omega$ incident from a perpendicular direction are described. As seen in FIG. 9, since a large number of cylindrical lens elements having a high-order aspheric face are arrayed successively, the light flux $\Omega$ can be refracted and transmitted forwardly of the lens sheet, and this contributes to enhancement of the luminance in the front face direction when compared with the conventional prism sheet.

<u>Light Flux $\Psi$ Incident from a Sideward Direction</u>

Now, action and effects of the lens sheet with

respect to a light flux Ψ incident from a sideward direction are described. As seen in FIG. 9, a light flux Ψ emitted from an imaginary light start point P just below a joining point B between aspheric faces and entering the AB face is totally reflected most by the AB face and is refracted or totally reflected by the AC face to form a return light component R. Therefore, the probability that the light flux Ψ may contribute to generation of side lobe light as a second-order transmission light component T2 can be reduced, and the light flux Ψ can contribute to enhancement of the luminance in the front face direction.

Furthermore, also on the face in the proximity of the vertex A on the side between the points A and C, the angle of a normal line to the face forms a shallow angle with respect to the Z axis with regard to a reflected light flux from the first totally reflecting face (AB face). Therefore, an effect that the reflected light flux is totally reflected to form the return light component R is exhibited.

Furthermore, part of the light flux Ψ incident to the AC face is distributed forwardly by a refraction effect provided by the curved face shape of the AC face.

Furthermore, also on the curved face in the

proximity of the vertex, the reflected light flux from the AB face undergoes a refraction transmission effect higher than that of the conventional prism shape and undergoes even a total reflection effect.

FIG. 10 illustrates a light distribution characteristic of the lens sheet of the working example 1. As seen in FIG. 10, with the lens sheet of the working example 1, the second-order transmission light component T2 is reduced when compared with the prism sheet of the conventional example described hereinabove.

In this manner, in the lens sheet of the working example 1, by improving the refraction and transmission effect to the front face side over an overall area from a perpendicular component direction described hereinabove and the refraction capacity and the total reflection capacity for an incident light flux from a side face direction, the first order transmission light can be increased thereby to raise the front face luminance while the light distribution is maintained in the forward direction. Further, by suppressing the second order transmission light component T2 to increase the contribution to the return light component R, the light can be utilized effectively, and therefore, the gain characteristic of light can be enhanced.

Then, the toroidal lens elements formed on one of the principal faces of the lens sheet in such a manner as described above and the toroidal lens element represented by $Z = X^2/(3 + \sqrt{}(9 + X^2)) + 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape. In other words, it was found that the thermoplastic resin can be advanced into a vertex portion of the lens pattern of each toroidal lens element and a desired toroidal lens shape can be obtained.

Working Example 2

(Where $R = 5$, $K = -10$, $A = 5 \times 10^{-5}$, $B$, $C \cdots = 0$)

FIG. 11 shows part of an XZ section of a lens sheet of a working example 2 in an enlarged scale. Cylindrical lens elements having a finite focal distance on the emission side of illumination light and having a leftwardly and rightwardly symmetrical, high-order aspheric face are arrayed successively on the lens sheet. This aspheric face is represented by $Z = X^2/(5 + \sqrt{}(25 + 9X^2)) + 5 \times 10^{-5}X^4$ which satisfies the expression (1).

In the following, action and effects of the lens sheet of the working example 2 with respect to a light flux $\Omega$ incident from a perpendicular direction and another light flux $\Psi$ incident from a sideward direction

are described with reference to FIG. 11.

As seen in FIG. 11, the sectional shape exhibits a curved face of a great curvature when compared with that of the sectional shape of the lens sheet of FIG. 9, and although the expansion of the refracted transmitted light of the light flux Ω is subject to a variation, the refracted transmitted light is distributed forwardly. Further, since the total reflection effect of the AB face and the AC face increases, the second order transmission light component T2 can be reduced. As regards the transmission direction through the AC face, the variation of the normal line direction increases and the incidence angle of the incident light flux becomes shallow. Therefore, although the refraction effect decreases, the forward light distribution is not deteriorated.

FIG. 12 illustrates a light distribution characteristic of the lens sheet of the working example 2. As shown in FIG. 12, with the lens sheet of the working example 2, the second order transmission light component T2 is reduced when compared with the conventional prism sheet described hereinabove.

Then, a lens sheet was produced in a similar manner as in the working example 1 described hereinabove, and the toroidal lens elements formed on one of the

principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(5 + \sqrt{(25 + 9X^2)}) + 5 \times 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

Working Example 3

(Where $R = 1$, $K = -2$, $A = 10^{-5}$, $B$, $C \cdots = 0$)

FIG. 13 shows part of an XZ section of a lens sheet of a working example 3 in an enlarged scale. Cylindrical lens elements having a finite focal distance on the emission side of illumination light and having a leftwardly and rightwardly symmetrical, high-order aspheric face are arrayed successively on the lens sheet. This aspheric face shape is represented by $Z = X^2/(1 + \sqrt{(1 + X^2)}) + 10^{-5}X^4$ which satisfies the expression (1).

In the following, action and effects of the lens sheet of the working example 3 with respect to a light flux $\Omega$ incident from a perpendicular direction and another light flux $\Psi$ incident from a sideward direction are described with reference to FIG. 13.

As seen in FIG. 13, part of a light flux $\Omega$ emitted from an imaginary light start point O is totally reflected by the face in the proximity of a point A and can auxiliary enhance the front face luminance as a

return light component R. Further, the efficiency in which a light flux Ψ emitted from another imaginary light start point P can be utilized as a return light component R by the total reflection and a refraction capacity for the light flux Ψ is raised to moderate appearance of the second-order transmission light component T2.

FIG. 14 is a distribution diagram representing the light distribution characteristic of the lens sheet of the working example 3. As shown in FIG. 14, with the lens sheet of the working example 3, the second order transmission light component T2 is reduced when compared with the prism sheet of the conventional example described hereinabove.

Then, a lens sheet was produced in a similar manner as in the working example 1, and the toroidal lens elements formed on one of the principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(1 + \sqrt{}(1 + X^2)) + 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

Working Example 4

(Where $R = 1$, $K = -2$, $A = 10^{-5}$, $B = 0$, $C = 2 \times 10^{-5}$, $D$, $E \cdots = 0$)

FIG. 15 shows part of an XZ section of a lens

sheet of a working example 4 in an enlarged scale. Cylindrical lens elements having a finite focal distance on the emission side of illumination light and having a leftwardly and rightwardly symmetrical, high-order aspheric face are arrayed successively on the lens sheet. This aspheric face is represented by $Z = X^2/(1 + \sqrt{}(1 + X^2)) + 10^{-5}X^4 + 2 \times 10^{-5}X^6$ which satisfies the expression (1).

In the following, action and effects of the lens sheet of the working example 4 with respect to a light flux Q incident from a perpendicular direction and another light flux Ψ incident from a sideward direction are described with reference to FIG. 15.

As seen in FIG. 15, part of a light flux Ω emitted from an imaginary light start point O is totally reflected by the face in the proximity of a point A and can auxiliary enhance the front face luminance as a return light component R. Further, the efficiency in which a light flux Ψ emitted from another imaginary light start point P can be utilized as a return light component R by the total reflection and a refraction capacity for the light flux Ψ is raised to moderate appearance of the second-order transmission light component T2.

FIG. 16 illustrates a light distribution

characteristic of the lens sheet of the working example 4. As shown in FIG. 16, with the lens sheet of the working example 4, the second order transmission light component T2 is reduced when compared with the prism sheet of the conventional example described hereinabove.

Then, a lens sheet was produced in a similar manner as in the working example 1, and the toroidal lens elements formed on one of the principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(1 + \sqrt{}(1 + X^2)) + 10^{-5}X^4 + 2 \times 10^{-5}X^6$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

<u>Working Example 5</u>

(Where $R = 25$, $K = -2$, $A = 5 \times 10^{-5}$, $B, C \cdots = 0$)

FIG. 17 shows part of an XZ section of a lens sheet of a working example 5 in an enlarged scale. FIG. 20 illustrates a visual field characteristic of the lens sheet of the working example 5. A cross section of cylindrical lens elements provided on a face of the lens sheet on the side from which light is emitted has an aspheric face sectional shape having a finite focal distance on the emission side of illumination light as seen in FIG. 17. The sectional shape is represented by the following expression which is obtained by

substituting $R = 25$, $K = -2$, $A = 5 \times 10^{-5}$, $B, C \cdots = 0$ into the expression (1):

$$Z = X^2/(25 + \sqrt{}(625 + 10X^2)) + 5 \times 10^{-5}X^4$$

In the following, action and effects of the lens sheet of the working example 5 with respect to a light flux Ω incident from a perpendicular direction and another light flux Ψ incident from a sideward direction are described with reference to FIG. 17.

<u>Light Flux Ω Incident from a Perpendicular Direction</u>

First, action and effects of the lens sheet with respect to the light flux Ω incident from a perpendicular direction are described. In the lens sheet of the working example 5, the incident light flux Ω is all refracted and transmitted forwardly of the lens sheet. Consequently, an effect that the distribution light ratio to the sheet front face direction can be increased can be achieved. In particular, in the lens sheet of the working example 5, since the first-order transmission light can all be refracted and transmitted forwardly due to the aspheric face shape provided on one of the principal faces, an effect that the characteristic of the first order transmission light can be improved can be achieved.

In contrast, in the prism sheet of the

conventional example described hereinabove, since part of the light flux Ω which is incident upon a portion in the proximity of a vertex from within the light flux Ω has an incident angle exceeding the critical angle $\theta c = \sin^{-1}(1/n)$, it is totally reflected to form return light. For example, where the sheet material is polycarbonate (n = 1.59), the light flux Ω having an incident angle exceeding the critical angle $\theta c = 38.97°$ is totally reflected to form return light. It is to be noted that part of the return light is re-introduced into the prism sheet by a diffuser or the like and then utilized effectively.

Light Flux Ψ Incident from a Sideward Direction

Now, action and effects of the lens sheet with respect to the light flux Ψ incident from a sideward direction are described. Part of the light flux Ψ is totally reflected by the AB face and is refracted or totally reflected by the AC face so that the probability that the totally reflected light flux Ψ may contribute to generation of side lobe light as second order transmission light is reduced. Meanwhile, the other part of the light flux Ψ incident on the AB face is refracted and transmitted so that it may form transmission light which expands the angular field of view without having an

influence on side robe light.

Here, paying attention to a portion of the AC face in the proximity of the vertex, in the lens sheet of the working example 5, a normal line to the AC face in the proximity of the vertex forms a shallow angle with respect to the Z axis. Accordingly, an effect that the reflected light flux Ψ from the AC face can be totally reflected by the portion of the AC face in the proximity of the vertex to form the return light can be achieved. In particular, in the prism sheet of the conventional example, the light flux Ψ incident on a portion of the AC face in the proximity of the vertex A from within the light flux Ψ coming to the AC face after reflected by the AB face forms side robe light. However, in the lens sheet of the working example 5, the light flux Ψ incident on the AC face in the proximity of the vertex A from within the light flux Ψ coming to the AC face after reflected by the AB face can be totally reflected to form return light.

Further, from within the light flux Ψ incident on the AC face from the imaginary start point P, the light flux Ψ in a region up to a portion of the AC face in the proximity of the joining point C is distributed forwardly by a refraction effect of the curved face. Therefore, an

expansion effect of the angular field of view can be anticipated. Further, the light flux Ψ in the proximity of the joining point C which is a light flux to a sideward direction which can originally become side robe light is refracted and transmitted by the AC face and re-enters an adjacent aspheric face side to form return light. Therefore, an effect that side robe light can be suppressed can be anticipated.

As described above, an overall forward refraction transmission effect of the incidence light flux Ω from a perpendicular direction, a refraction capacity and a total reflection capacity for the incident light flux Ψ from a sideward direction and a return light effect of side face distribution light can be enhanced. Consequently, the first order transmission light can be increased to raise the front face luminance while the light distribution is maintained in the forward direction. Further, the second order transmission light can be suppressed to give rise to an expansion effect of the angular field of view. Furthermore, the contribution to return light can be increased to implement effective utilization of light (refer to FIG. 18).

Then, a lens sheet was produced in a similar manner as in the working example 1 described hereinabove,

and the toroidal lens elements formed on one of the principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(25 + \sqrt{}(625 + 10X^2)) + 5 \times 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

<u>Working Example 6</u>

(Where $R = 10$, $K = -41$, $A = 6 \times 10^{-5}$, $B, C \cdots = 0$)

FIG. 19 shows part of an XZ section of a lens sheet of a working example 6 in an enlarged scale. FIG. 20 illustrates a visual field characteristic of the lens sheet of the working example 6. A cross section of cylindrical lens elements provided on a face of the lens sheet on the side from which light is emitted has an aspheric face sectional shape having a finite focal distance as seen in FIG. 19. The sectional shape is represented by the following expression which is obtained by substituting $R = 10$, $K = -41$, $A = 6 \times 10^{-5}$, $B, C \cdots = 0$ into the expression (1):

$$Z = X^2/(10 + \sqrt{}(100 + 40X^2)) + 6 \times 10^{-5}X^4$$

From FIGS. 19 and 20, it can be seen that the lens sheet of the working example 6 can achieve action and effects similar to those of the lens sheet of the working example 5 described hereinabove with respect to

the light flux Ω incident from a perpendicular direction and the light flux Ψ incident from a sideward direction.

Then, a lens sheet was produced in a similar manner as in the working example 1 described hereinabove, and the toroidal lens elements formed on one of the principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(10 + \sqrt{}(100 + 40X^2)) + 6 \times 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

Working Example 7

(Where $R = 40$, $K = -201$, $A = 6 \times 10^{-5}$, $B, C \cdots = 0$)

FIG. 21 shows part of an XZ section of a lens sheet of a working example 7 in an enlarged scale. FIG. 22 illustrates a orientation characteristic of the lens sheet of the working example 7. A cross section of cylindrical lens elements provided on a face of the lens sheet on the side from which light is emitted has an aspheric face sectional shape having a finite focal distance as seen in FIG. 21. The sectional shape is represented by the following expression which is obtained by substituting $R = 40$, $K = -201$, $A = 6 \times 10^{-5}$, $B, C \cdots = 0$ into the expression (1):

$$Z = X^2/(40 + \sqrt{}(1600 + 200X^2)) + 6 \times 10^{-5}X^4$$

From FIGS. 21 and 22, it can be seen that the lens sheet of the working example 6 can achieve action and effects similar to those of the lens sheet of the working example 5 described hereinabove with respect to the light flux Ω incident from a perpendicular direction and the light flux Ψ incident from a sideward direction.

Then, a lens sheet was produced in a similar manner as in the working example 1 described hereinabove, and the toroidal lens elements formed on one of the principal faces of the lens sheet and the toroidal lens element represented by $Z = X^2/(40 + \sqrt{(1600 + 200X^2)}) + 6 \times 10^{-5}X^4$ specified as above were compared in shape with each other. As a result, it was found that the two have a substantially same shape.

Further, as shown in FIGS. 8, 18, 20 and 22, the angular field of view according to a half value width with respect to the front face luminance exhibits the following values in the conventional example and the working examples 5 to 7:

Conventional example: 100°

Working example 5: 145°

Working example 6: 145°

Working example 7: 150°

Accordingly, while the conventional prism sheet

has a problem that the angular field of view is approximately 100° and is narrow, the lens sheets of the working examples 5 to 7 have an advantage that the angular field of view is approximately 150° and is wide. In other words, the lens sheets of the working examples 5 to 7 can achieve a superior effect that the angular field of view can be enhanced significantly when compared with the conventional prism sheet.

It can be recognized that, from the working examples 1 to 4 described above, the following effects can be achieved by applying the conditions of $0 < R \leqq 30$, $R - K \geqq 5$, $-15 < K \leqq -1$, $0 < A, B, C \cdots < 10^{-3}$ to the expression (1). In particular, it can be recognized (1) that the highest luminance can be obtained in the front face direction, (2) that a high luminance distribution can be implemented in a direction within a predetermined angular field of view, (3) that the second order transmission light can be suppressed.

Further, it can be recognized that, from the working examples 5 to 7 described above, the following effects can be achieved by applying the conditions of $0 \geqq R$, $K < -1$, $0 < A < 10^{-3}$, $0 \leqq B, C \cdots < 10^{-3}$ to the expression (1). In particular, it can be recognized (1) that the highest luminance can be obtained in the front

face direction, (2) that a high luminance distribution can be implemented in a direction within a predetermined angular field of view, (3) that the second order transmission light can be suppressed, and (4) that the angular field of view can be expanded.

Now, results of a study regarding numerical values of the radius R of curvature of the distal end vertex, the conic constant K and the aspheric coefficients A, B, C ··· based on a peak luminance distribution are described.

<u>Working Example 8</u>

(Where K = -1)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -1 was substituted was determined. FIG. 23 illustrates a peak luminance distribution in the case of the conic constant K = -1.

<u>Working Example 9</u>

(Where K = -1.5)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the

expression (1) given hereinabove into which the conic constant K = -1.5 was substituted was determined. FIG. 24 illustrates a peak luminance distribution in the case of the conic constant K = -1.5.

Working Example 10

(Where K = -2)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -2 was substituted was determined. FIG. 25 illustrates a peak luminance distribution in the case of K = -2.

Working Example 11

(Where K = -5)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -5 was substituted was determined. FIG. 26 illustrates a peak luminance distribution in the case of K = -5.

Working Example 12

(Where K = -10)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -10 was substituted was determined. FIG. 27 illustrates a peak luminance distribution in the case of K = -10.

Working Example 13

(Where K = -15)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -15 was substituted was determined. FIG. 28 illustrates a peak luminance distribution in the case of K = -15.

Working Example 14

(Where K = -20)

A peak luminance distribution in response to a variation of the radius R of curvature of the distal end vertex and the aspheric coefficient A according to the expression (1) given hereinabove into which the conic constant K = -20 was substituted was determined. FIG. 29 illustrates a peak luminance distribution in the case of

K = -20.

Now, results of a study regarding the convex portions provided on the rear face side of a lens sheet are described.

<u>Working Example 15</u>

First, an elastic roll was produced in the following manner. A seamless tube was formed by Ni plating, and a Cr plating process was performed for the surface of the seamless tube. Thereafter, the plated Cr layer was polished to 0.2 S to produce a seamless tube (hereinafter referred to as flexible sleeve) having a thickness of 340 microns. Then, the outer circumferential face of the flexible sleeve was processed with a stainless steel material (SUS material).

Then, glass beads having a predetermined particle size (diameter) were blasted into the flexible sleeve by a bead blast processing machine produced by Fuji Manufacturing Co., Ltd. to form a concave and convex shape on the outer circumferential face of the flexible sleeve. It is to be noted that the blasting angle was approximately 30° with respect to a normal line to the outer circumferential face of the flexible sleeve.

Then, an elastic member was adhered to a roll in which coolant can be circulated and the flexible sleeve

was fitted on the elastic member to obtain an elastic roll having a configuration that cooling water is circulated between the resilient member and the flexible sleeve. It is to be noted that, as the resilient member, nitrile-butadiene rubber (NBR) having a hardness of 85 degrees was used and the thickness thereof was set to 20 mm. Further, the diameter Φ of the elastic roll was set to 260 mm and the face length (width of the molding roll) was set to 450 mm.

Then, the elastic roll obtained in this manner was attached to an extruded sheet precision molding apparatus, and a lens sheet was produced in the following manner.

First, the polycarbonate E2000R (by Mitsubishi Engineering-Plastic Corporation) was successively discharged from the T die until it was nipped by the forming roll and the elastic roll, and then was wrapped around the forming roll. It is to be noted that the surface temperature of the forming roll was kept at Tg + 35°C, and the surface temperature of the lens sheet 14 was kept at 75°C. Here, Tg is the glass transition temperature of the polycarbonate resin.

Thereafter, the sheet was exfoliated from the forming roll by the cooling roll. It is to be noted that

the surface temperature of the cooling water was kept at 115°C. Further, the speed of the takeup machine was set to 7 m/min. From the foregoing, a lens sheet of 200 μm thick having the cylindrical lens elements provided on the front face thereof and having convex portions provided on the rear face thereof was obtained.

The surface temperatures of the forming roll and the elastic roll described above were measured at a position immediately preceding to the nip at which the measurement is least likely to be influenced by the heat of the resin while a sensor was contacted with the surface of the rolls. Further, the surface temperature of the cooling roll was measured at a position at which the sheet was nipped by the cooling roll and the forming roll while a sensor was contacted with the surface of the cooling roll. It is to be noted that, as the thermometers, a handy type digital thermometer (by Chino Corporation, commodity name: ND511-KHN) was used, and as the sensors, a sensor for surface temperature measurement (Anritsu Meter Co., Ltd., commodity name U-161K-00-D0-1) was used.

Working Examples 16 to 25

Lens sheets were obtained in a similar manner as in the working example 1 described hereinabove except

that a concave and convex shape was formed on an outer circumferential face of a flexible sleeve using glass beads having a particle size (diameter) different among the different working examples and an elastic roll having the flexible sleeve provided thereon was used to form the rear face side of the sheet.

Then, evaluation of the number of convex portions provided on the rear face side of the lens sheets of the working examples 15 to 25 obtained in such a manner as described above, the distance between the convex portions, the ten-point average roughness, the height of the convex portions at which the convex portion area occupies 1%, the dynamic coefficient of friction, the front face luminance relative value, the sliding test and the external appearance blurring was conducted.

Evaluation of the Number of Convex Portions

The rear face of the lens sheets was measured by a three-dimensional measuring instrument (by Kosaka Ltd., commodity name: E4100). Then, the measured surface shape was subject to oblique arithmetic operation-correction of a measurement oblique face by the least squares method to obtain an average central plane (JIS B0601-1994). Thereafter, the number of convex portions having a height equal to or greater than 0.20 μm from the average central

face was calculated.

Evaluation of the Distance between Convex Portions

An average distance between those convex portions having a height of 0.2 μm from the average central plane described above was determined.

Evaluation of the Ten-Point Average Roughness

Further, the differences between five greatest heights and five greatest valley heights from the average central plane described above were averaged to calculate the ten-point average roughness SRz.

Evaluation of the Height of those Convex portions at Which the Convex Portion Area Occupies 1%

The height from a certain central plane to a cutting plane along which the convex portions were cut in parallel to the central plane when, within a projection range from a normal direction to the central plane, the ratio of the total area of the cross sections of the convex portions was 1% with respect to the projection area was determined. The height at which the sectional area exhibited the area ratio of 1% (5,000 $\mu m^2$) was determined within a range of 1,000 μm × 500 μm.

Evaluation of the Dynamic Coefficient of Friction

A surface measuring instrument (by Shinto Scientific Co., Ltd., commodity name: Type-22) was used

to measure the friction of the lens sheet rear face side with respect to the diffusion sheet BS702 by Keiwa as an object of sliding motion with a load of 200 g.

Evaluation of the Front Face Luminance Relative Value

In order to evaluate actual machine characteristics, a lens sheet was mounted on a 19-inch TV (television) set on the market manufactured by Sony. In particular, a diffuser for mixture of light and non-uniformity elimination and a lens sheet of a working example were mounted successively on a unit in which a cold cathode fluorescent tube (CCFL) was accommodated to form a backlight system, and a liquid crystal panel was mounted on the backlight system to obtain a liquid crystal display apparatus. Then, the front face luminance of the liquid crystal display apparatus was measured by means of the CS-1000 by Konica Minolta.

Then, a lens sheet produced in a similar manner to a working example except that the formation of convex portions on the rear face side was omitted was mounted similarly on a 19-inch TV receiver on the market manufactured by Sony to obtain a liquid crystal display apparatus, and the front face luminance of the liquid crystal display apparatus was measured by means of the CS-1000 by Konica Minolta.

Then, the relative value of the front face luminance of the former liquid crystal display apparatus was determined with reference to the front face luminance of the latter liquid crystal display apparatus.

Evaluation by a Sliding Test

A surface measuring instrument (by Shinto Scientific Co., Ltd., commodity name: Heiden Type-22) was used to perform a sliding test between the rear surface of a lens sheet and a diffuser (MS resin). It is to be noted that the load was set to 200 g and the number of times of reciprocating sliding movement was set to 100. Then, a scar of the sliding face was observed through a backlight unit for observation of a photographic negative on the market, and the degree of the scar was evaluated into three stages including (1) that a few scars exist, (2) that several scars exit and (3) that scars exist over an overall area.

Evaluation of the External Appearance Blurring

When a lens sheet was mounted on a 19-inch TV receiver on the market manufactured by Sony to observe a liquid crystal panel in a similar manner as in the case of the evaluation of the front face luminance relative value described above, it was confirmed by visual observation whether or not a blurring state on an

external appearance (ununiformity in luminance) was observed while the observation direction was successively changed.

Working Examples 26 to 36

Lens sheets having no lenses provided on the front face side and having a concave and convex shape provided on the rear face side were obtained in a similar manner as in the working examples 15 to 25 described hereinabove except that a forming roll having a mirror face-like molding face was prepared and used to prepare a lens sheet.

Evaluation of the Haze

The haze (degree of cloudiness) of the lens sheets of the working examples 26 to 36 obtained in such a manner as described above was measured using a haze meter (by Murakami Color Research Laboratory, commodity name: HM-150).

Evaluation of the Average Inclination Gradient

The average inclination gradient of the lens sheets of the working examples 22 to 32 obtained in such a manner as described above was determined.

The average inclination gradient is given by the following expression where the rectangular coordinate axes of the X and Y axes are placed on the center of a

roughness curve and an axis perpendicular to the center plane is set as the Z axis and the roughness curve is represented by f(x, y) while the size of the reference plane is represented by Lx and Ly:

$$\delta a = \frac{1}{S_M}\int_0^{Lx}\int_0^{Ly}\sqrt{\left(\frac{\delta f}{\delta x}\right)^2 + \left(\frac{\delta f}{\delta y}\right)^2}\,dxdy$$

$$S_M = Lx \times Ly$$

FIGS. 30 and 31 illustrate results of the evaluation obtained in such a manner as described above. It is to be noted that numerals in the column of a decision result of the sliding test indicates the following decision results.

1: scars exist over an overall area, 2: several scars exist, 3: a few scars exist

FIG. 32 is a graph illustrating a relationship between the number of those convex portions equal to or greater than 0.2 μm and the luminance relative value. FIG. 33 is a graph illustrating a relationship between the number of those convex portions equal to or greater than 0.2 μm and the external appearance blurring. FIG. 34 is a graph illustrating a relationship between the distance between those convex portions equal to or greater than 0.2 μm and the luminance relative value. FIG. 35 is a graph illustrating a relationship between

the distance between those convex portions equal to or greater than 0.2 μm and the sliding test result. FIG. 36 is a graph illustrating a relationship between the number of those convex portions equal to or greater than 0.2 μm and the external appearance blurring. FIG. 37 is a graph illustrating a relationship between the ten-point average roughness SRz and the luminance relative value. FIG. 38 is a graph illustrating a relationship between the ten-point average roughness SRz and the sliding test result. FIG. 39 is a graph illustrating a relationship between the height at which the convex portion area occupies 1% and the luminance relative value. FIG. 40 is a graph illustrating a relationship between the height at which the convex portion area occupies 1% and the sliding test result. FIG. 41 is a graph illustrating a relationship between the haze and the luminance relative value. FIG. 42 is a graph illustrating a relationship between the average inclination gradient and the luminance relative value.

From the evaluation results of FIGS. 30 to 41, the followings can be recognized.

Evaluation Results of the Number of Convex Portions

From the evaluation result of the external appearance blurring (refer to FIG. 33), it can be

recognized that, by setting the density of convex portions equal to or greater than 70 /mm$^2$, the external appearance blurring caused by interference of the diffuser provided on the rear face side of a lens sheet with the flat face portion can be improved.

Further, from the evaluation result of the front face luminance relative value (refer to FIG. 32), it can be recognized that, by setting the density of convex portions equal to or lower than 400 /mm$^2$, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex portions on the rear face side of a lens sheet can be suppressed.

Evaluation Results of the Distance between the Convex Portions

From the evaluation result of the front face luminance relative value (refer to FIG. 34), it can be recognized that, by setting the average distance between the convex portions equal to or more than 50 μm, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex portions on the rear face side of a lens sheet can be suppressed.

Further, from the evaluation result of the sliding test and the evaluation result of the external appearance blurring (refer to FIGS. 35 and 36), it can be

recognized that, by setting the average distance between the convex portions equal to or smaller than 120 μm, formation of scars on the surface of the diffuser by the rear face of the lens sheet can be prevented and the external appearance blurring caused by interference of the diffuser provided on the rear face side of the lens sheet with the flat face portion can be improved.

Evaluation Results of the Ten-Point Average Roughness

From the evaluation result of the sliding test and the evaluation result of the external appearance blurring (refer to FIGS. 30 and 38), it can be recognized that, by setting the ten-point average roughness SRz of the convex portions equal to or higher than 1 μm, formation of scars on the surface of the diffuser by the rear face of the lens sheet can be prevented and the external appearance blurring caused by interference of the diffuser provided on the rear face side of the lens sheet with the flat face portion can be improved.

From the evaluation result of the front face luminance relative value (refer to FIG. 37), it can be recognized that, by setting the ten-point average roughness SRz of the convex portions equal to or less than 15 μm, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex

portions on the rear face side of a lens sheet can be suppressed.

<u>Evaluation Results of the Height of the Convex Portions at Which the 1% Area Is Exhibited</u>

From the evaluation result of the sliding test and the evaluation result of the external appearance blurring (refer to FIGS. 30 and 40), it can be recognized that, by setting the height of the convex portions at which the convex portion area occupies 1% equal to or greater than 1 μm, formation of scars on the surface of the diffuser by the rear face of the lens sheet can be prevented and the external appearance blurring caused by interference of the diffuser provided on the rear face side of the lens sheet with the flat face portion can be improved.

Further, from the evaluation result of the front face luminance relative value (refer to FIG. 39), it can be recognized that, by setting the height of the convex portions at which the convex portion area occupies 1% equal to or smaller than 7 μm, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex portions on the rear face side of a lens sheet can be suppressed.

<u>Evaluation Result of the Haze</u>

From the evaluation result of the front face luminance relative value (refer to FIG. 41), it can be recognized that, by setting the haze of a lens sheet in a state wherein no lens pattern is formed equal to or lower than 60%, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex portions on the rear face side of a lens sheet can be suppressed. Further, it can be recognized that, by setting the haze of a lens sheet in a state wherein no lens pattern is formed equal to or lower than 20%, a drop of the luminance of a liquid crystal display apparatus caused by provision of the convex portions on the rear face side of a lens sheet can be further suppressed.

Evaluation Result of the Average Inclination Gradient

From the evaluation result of the front face luminance relative value (refer to FIG. 42), it can be recognized that, by setting the average inclination gradient $\delta a$ in a state wherein no lens pattern is formed equal to or lower than 0.25 (rad), a drop of the luminance of a lens sheet can be suppressed.

As described above, by providing convex portions on the rear face of a lens sheet, improvement in the external appearance blurring and improvement in the mechanical characteristics such as a sliding

characteristic can be achieved without degrading the luminance. It is considered that the reduction of the external appearance blurring is caused by prevention of sticking to the diffuser by the convex portions. Further, it is considered that the improvement of the sliding test characteristic is caused by reduction of the friction upon sliding by the convex portion components.

The present invention is not restricted to the working examples of the present invention described above, but various modifications and applications can be made without departing from the spirit and scope of the present invention. For example, a similar improvement effect of the front face luminance can be anticipated by disposition above a light guide plate.

Further, similar effects can be exhibited even where the lens sheet is disposed on the light emitting side face of the backlight from a light guide plate within a display unit which utilizes liquid crystal or even where the lens sheet is disposed on the incidence side front portion of a liquid crystal display panel.

Further, while, in the working examples described above, a case wherein one lens sheet is provided in a backlight and a liquid crystal display apparatus is described as an example, a plurality of lens sheets may

be provided.

Further, the backlight 1 is not limited to the one working example described hereinabove, but may be configured such that it includes the lens sheet 14 above a light guide plate, an EL (Electro Luminescence) light emitting face, a planar light emitting CCFL (Cold Cathode Fluorescent Tube) or some other light source. Also in this instance, a front face luminance improvement effect similar to that of the one embodiment described hereinabove can be achieved.

While, in the one working example described hereinabove, a case wherein a lens sheet is produced by a melt extrusion method is described, the lens sheet may be produced by a thermal press method. For example, a bead blasting or sand blasting machine on the market is used and the type of particles, particle size and shot speed are varied to produce a concave and convex shape on the face of the press plate for forming the rear face. A lens sheet can be obtained by vacuum thermoforming a thermoplastic resin using the press plate obtained in this manner and a press plate on which a concave and convex shape for forming cylindrical lens elements.

A production method of the lens sheet by a melt extrusion method is described more particularly.

First, glass beads having a particle size are blasted into an SUS material plate on the market having a thickness t of, for example, t = 1 mm by a bead blast processing machine by Fuji Manufacturing Co., Ltd. to produce a press plate for forming the rear face side of a lens sheet. Thereupon, the blasting angle is set, for example, to an angle of approximately 30° with respect to a perpendicular direction to the SUS material plate.

Then, a sheet of a thickness t of t = 200 μm made of, for example, polycarbonate or the like is sandwiched between the press sheet obtained in such a manner as described above and a metal mold having a lens pattern provided thereon and is press formed for 10 minutes at 170°C × 10 kg/cm$^2$, for example, by a vacuum thermal press machine, whereafter it is cooled to a room temperature. An object lens sheet is obtained thereby.

Further, while, in the one working example described hereinabove, an example wherein the convex portions 16 are provided on the cylindrical face of the elastic roll 24 to form the convex portions 16 on the rear face of the lens sheet 14 is described as an example, the shape of the cylindrical face of the elastic roll 24 is not limited to this. For example, where the rear face of the lens sheet 14 is to be formed as a flat face, the

cylindrical face of the elastic roll 24 may be formed as a mirror face.

Further, in the one working example described hereinabove, the liquid crystal display apparatus may further includes a protect sheet for preventing damage to the lens sheet 14. One of principal faces of the protect sheet is formed as a flat face while the other principal face is formed as a concave and convex face having convex portions provided thereon similarly to the rear face of the lens sheet 14. Where convex portions are to be formed only on one face of the protect sheet, the protect sheet is provided on the liquid crystal display apparatus in such a manner that the face of the protect sheet on which the convex portions are provided is opposed to the light sources 12. It is to be noted that the convex portions may be provided on the opposite faces of the protect sheet.

The protect sheet may be provided, for example, between the lens sheet 14 and the reflection type polarizer 18. Or, a protect sheet may be provided in place of the reflection type polarizer 18.